

Cosmic Microwave Background Program

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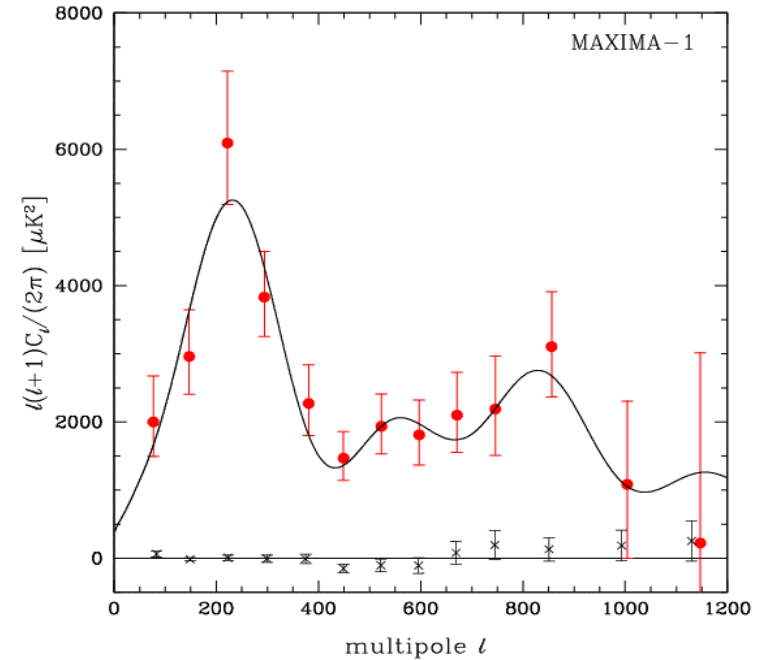
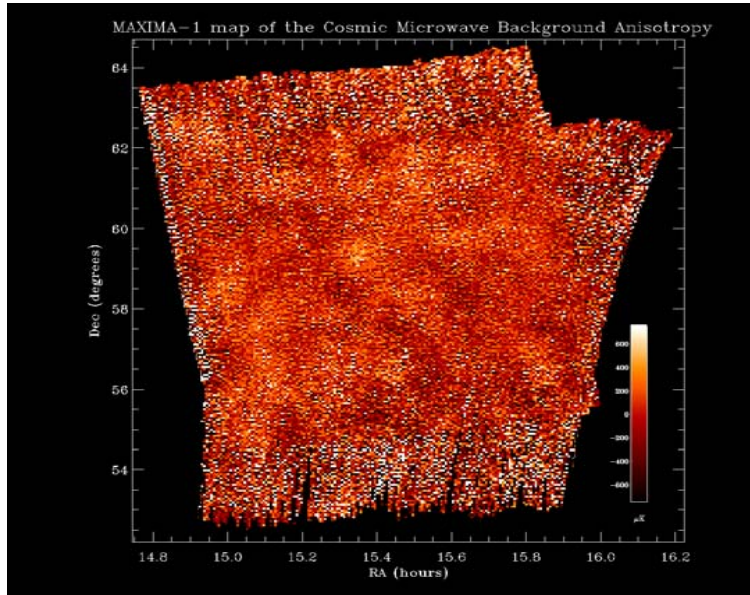
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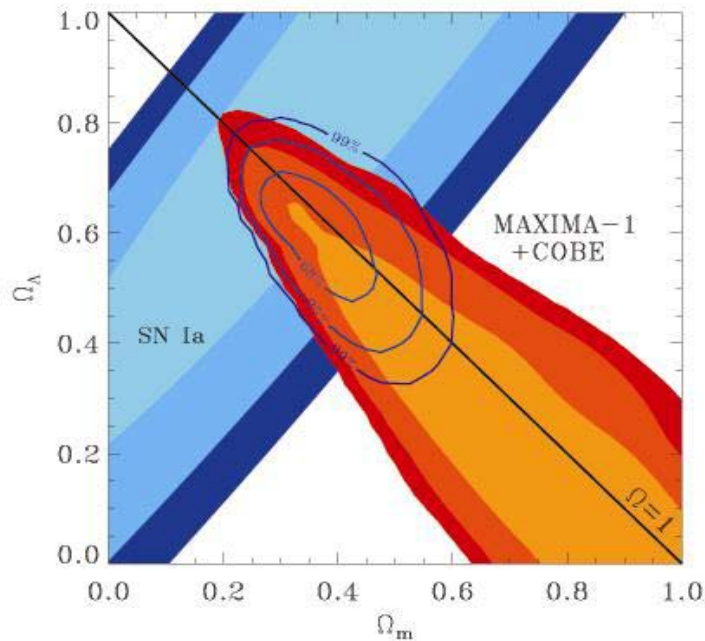
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MAXIMA

Berkeley (UC,LBNL), U. Minn, JPL, Rome, CIT, Oxford, QMWC



- Balloon-borne, Bolometer array @ 100 mK
- MAXIMA and BOOMERanG 1998 discoveries:
 - Rise and Fall of first peak
 - Quantitative Measurement of Ω_{tot} , Ω_b , and n



CMB Results

- Data consistent with flat Universe
- Baryon fraction agrees with BBN
- With supernovae or LSS => Λ term

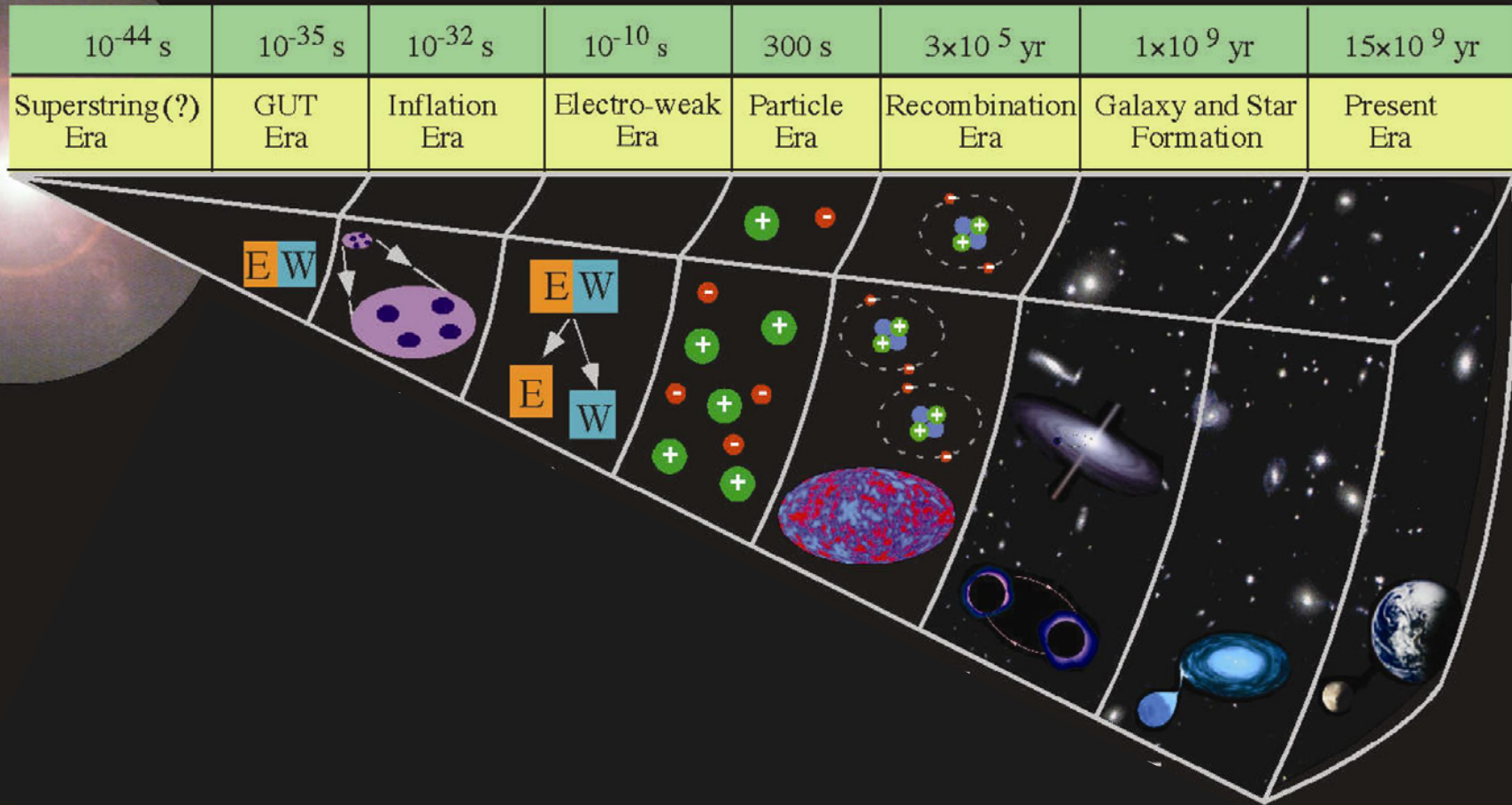
68% Confidence

Experiment	$\Omega_b h^2$	$\Omega_{cdm} h^2$	Ω_{tot}	n_s	Prior	Reference
DASI	$.022^{+.004}_{-.003}$	$.14 \pm .04$	$1.04 \pm .06$	$1.01^{+.08}_{-.06}$	$h > 0.45; \tau = 0$	Pryke <i>et al.</i>
BOOM	$.022^{+.004}_{-.003}$	$.13 \pm .05$	$1.02 \pm .06$	$0.96^{+.10}_{-.09}$	$0.4 < h < 0.9$	Netterfield <i>et al.</i>
MAXIMA	$.033^{+.007}_{-.007}$	$.17^{+.08}_{-.04}$	$0.90^{+.09}_{-.08}$	0.99 ± 0.07	$0.4 < h < 0.9$	Stompor <i>et al.</i>

Polarization Science

Big Bang

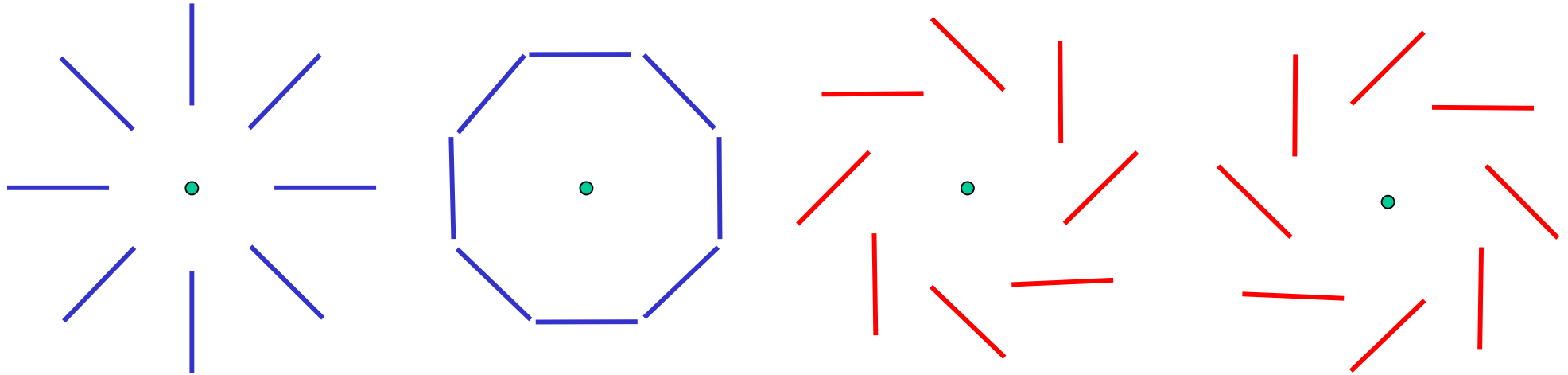
Time →



Gravity Waves from Inflation

- Gravity waves put stress on photon-baryon fluid
 - Generation of B-mode polarization
- Detection \Rightarrow “smoking gun” of inflation
- Amplitude of B-mode gives Energy Scale
 - One possibility: GUT level 10^{16} GeV
 - 12 orders of magnitude higher energy than accelerators!
- Observable evidence of String Theory?

E-modes and B-modes

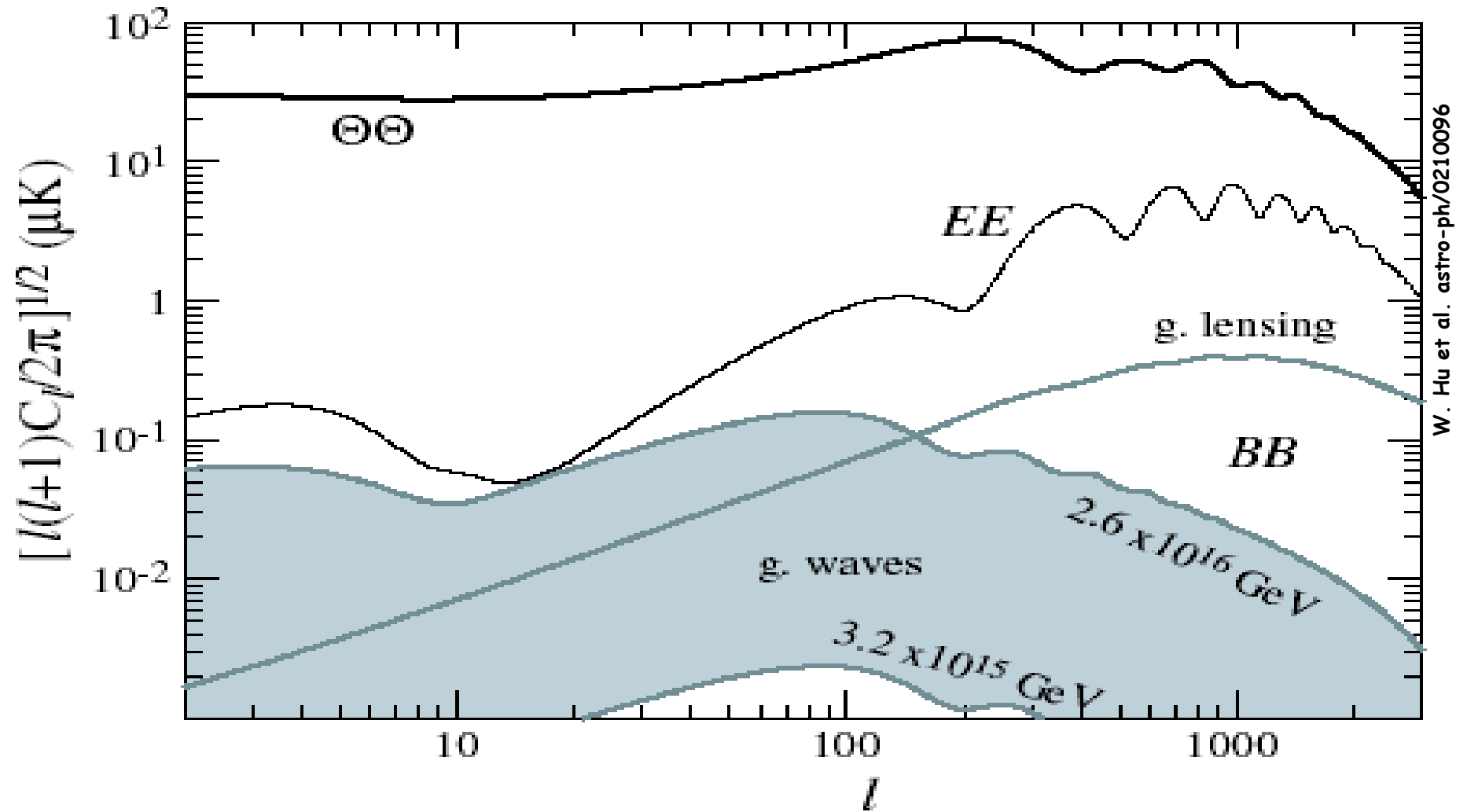


E-mode

B-mode

- Density fluct. give **scalar** perturbations \Rightarrow E-mode
- Gravity Waves give **tensor** perturbations \Rightarrow B, E modes
- Defects and strings give **vector** perturbations \Rightarrow B-mode

CMB Polarization Spectra

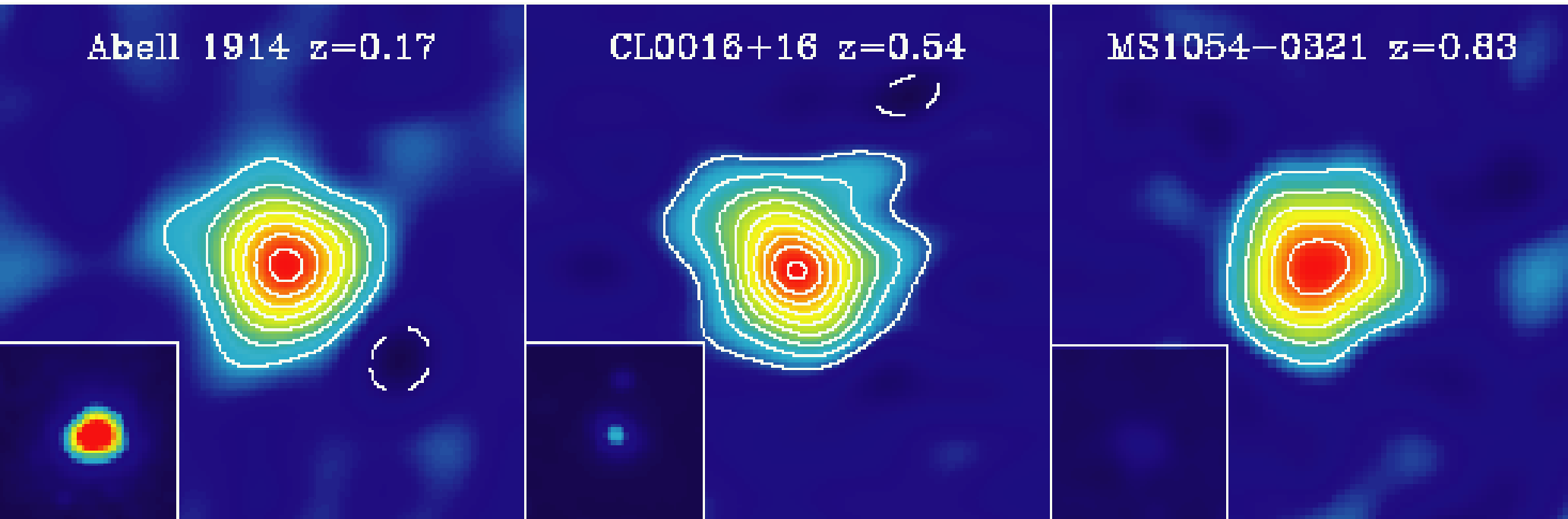


We need a large increase in sensitivity!

Galaxy Cluster Survey using SZ Effect

Science Case

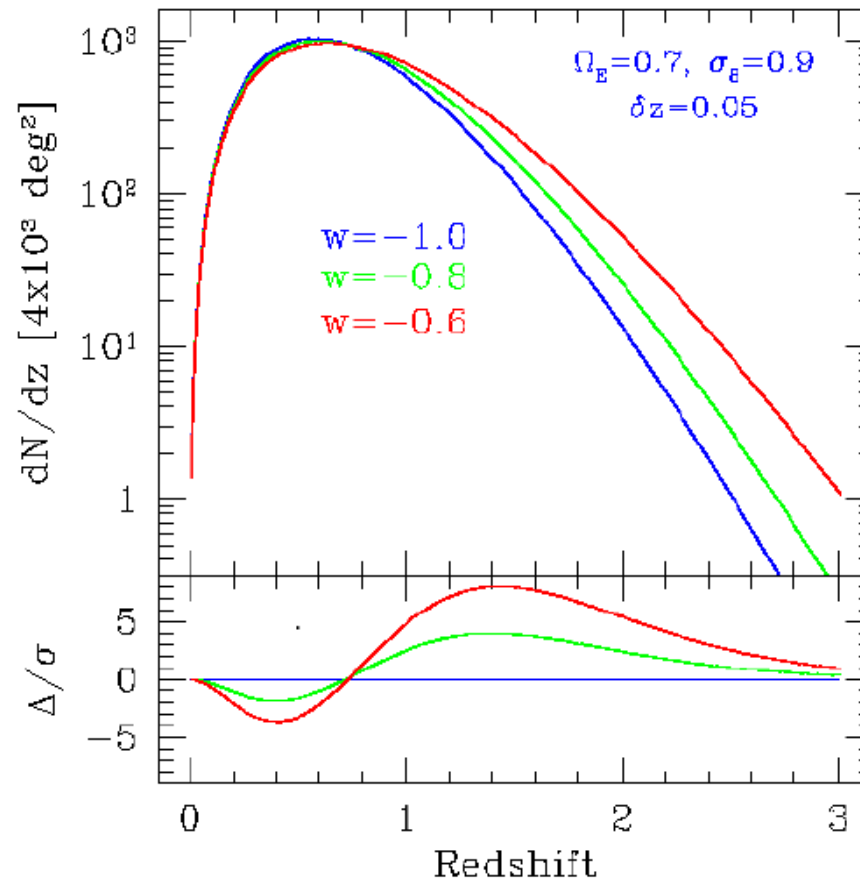
SZ Observations



In contrast to X-ray emission, SZ surface brightness is independent of cluster redshift, clusters can be seen at any distance!

Galaxy Cluster Surveys Probe Dark Energy

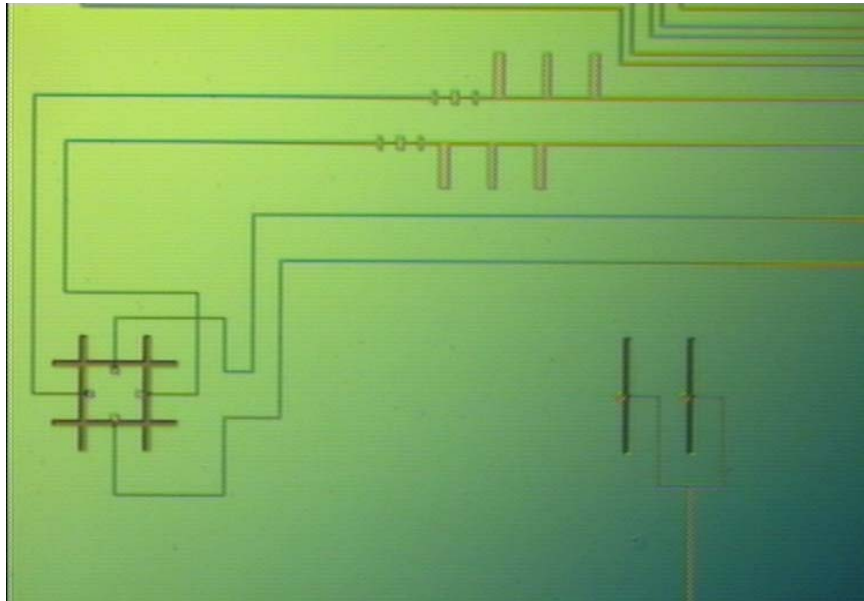
Cluster surveys probe (1) **volume-redshift relation**, (2) **abundance evolution**, (3) **structural evolution**



Large Focal Plane Bolometer-Arrays

- Approaching single pixel photon noise limit
 - Next Step: Large format bolometer arrays
- Transition-edge Sensor Bolometer
 - Entire fabrication is by optical photolithography
 - Multiplexed readout in development

New Detector Technology: Antenna Coupled Bolometer



1 mm

- Fabricated in UCB Microlab by M. Meyers
- Testing is underway

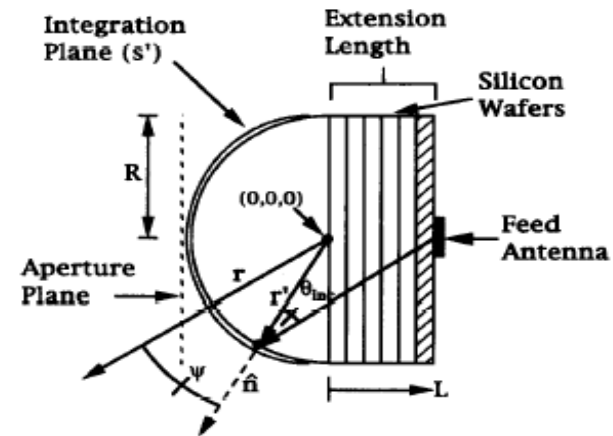


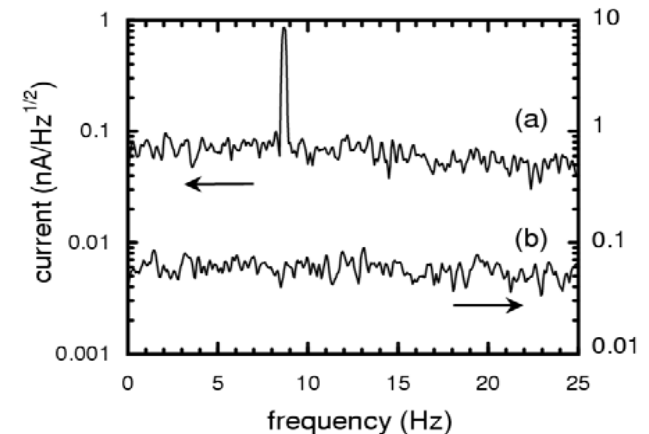
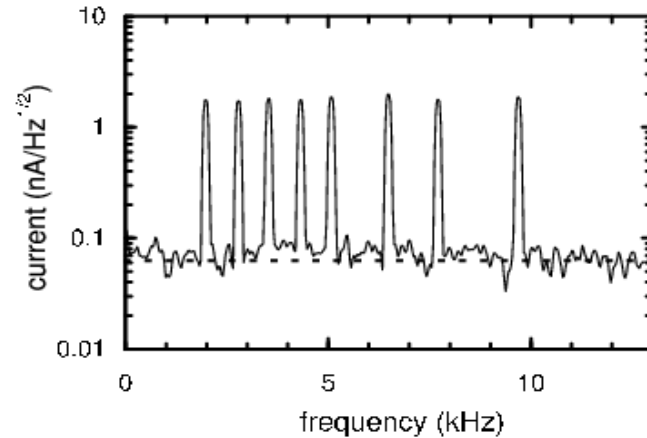
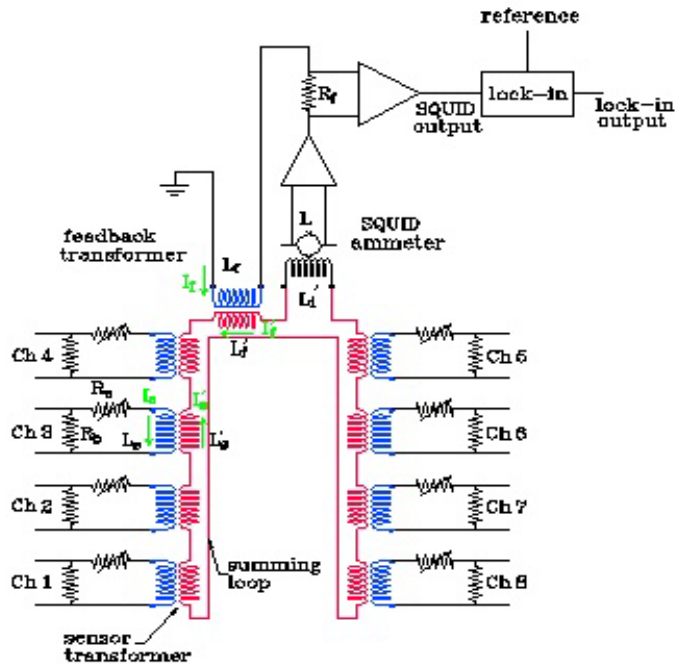
Fig. 1. The extended hemispherical lens and the ray-tracing/field-integration technique.

Silicon Lens used to focus the beam

Filipovic et. al. 1993

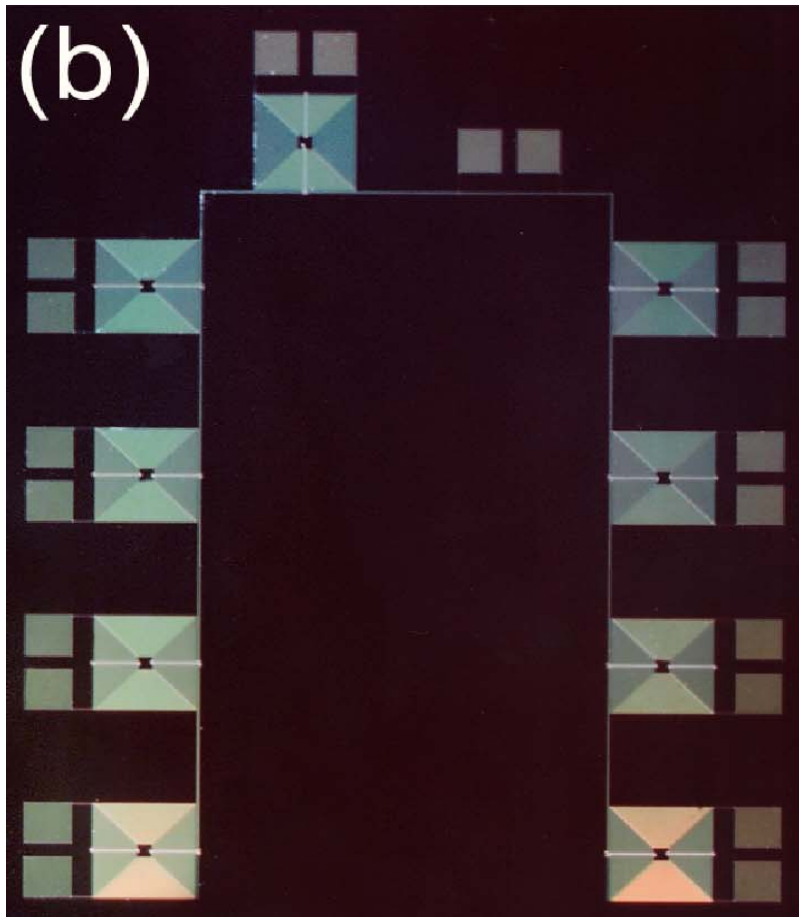
Single SQUID multiplexer

- One SQUID per row
- AC-bias \Rightarrow sum signals \Rightarrow demodulate

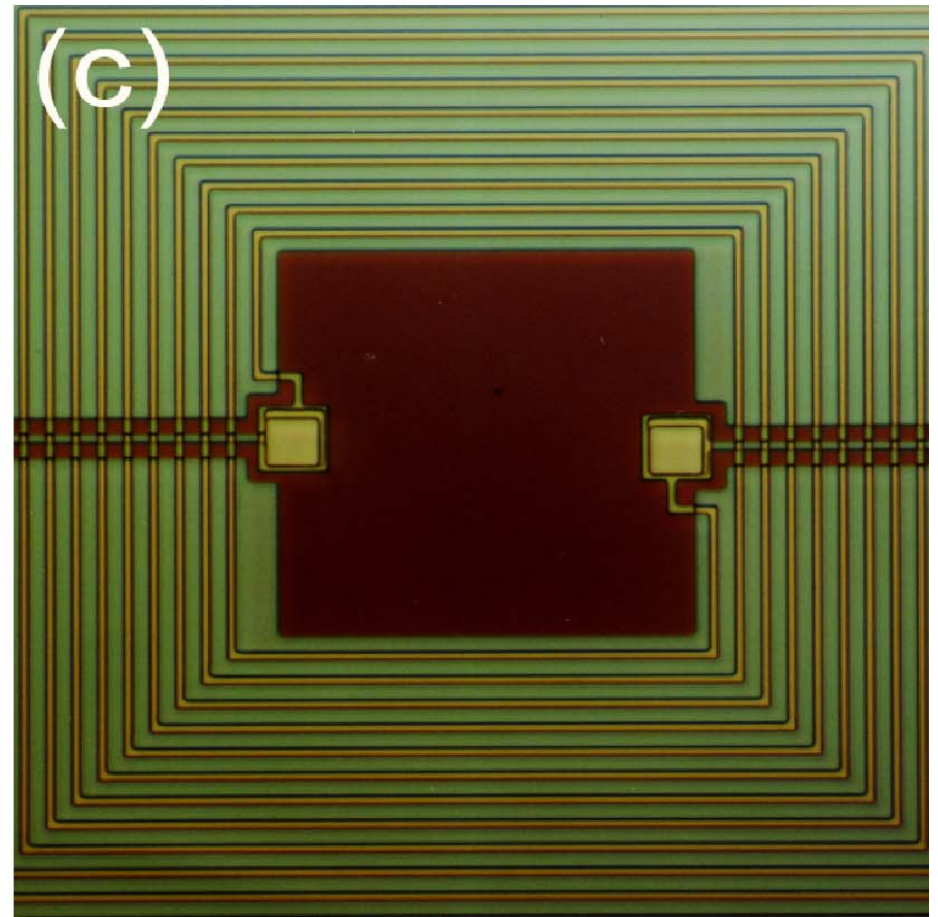


- 8-ch prototype tested with resistors
- Bolometer test
 - Increase SQUID slewrate
 - Use resonant filter to reduce Johnson noise

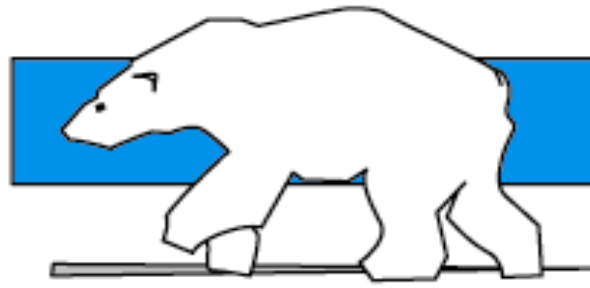
Multiplexer superconducting summing loop



1 mm

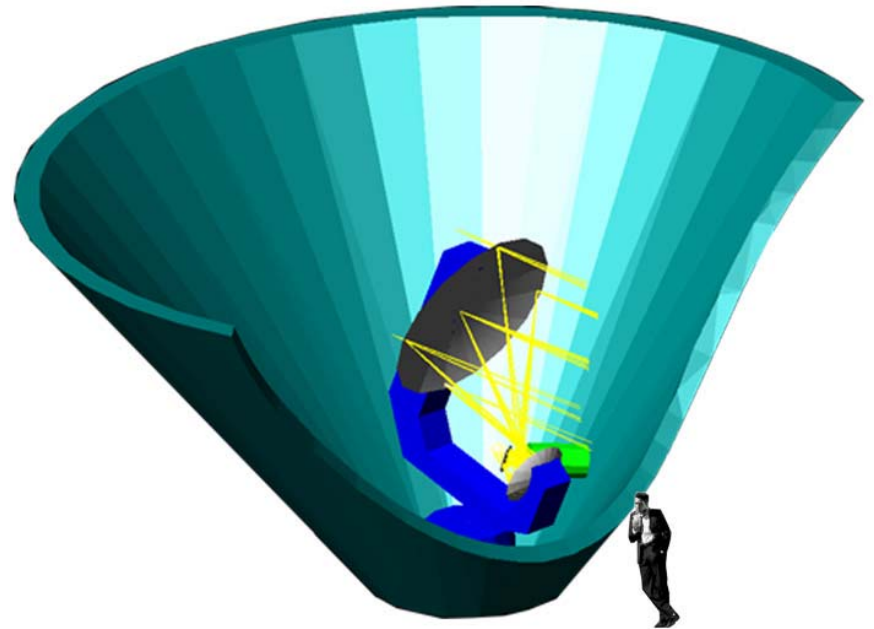


100 μm



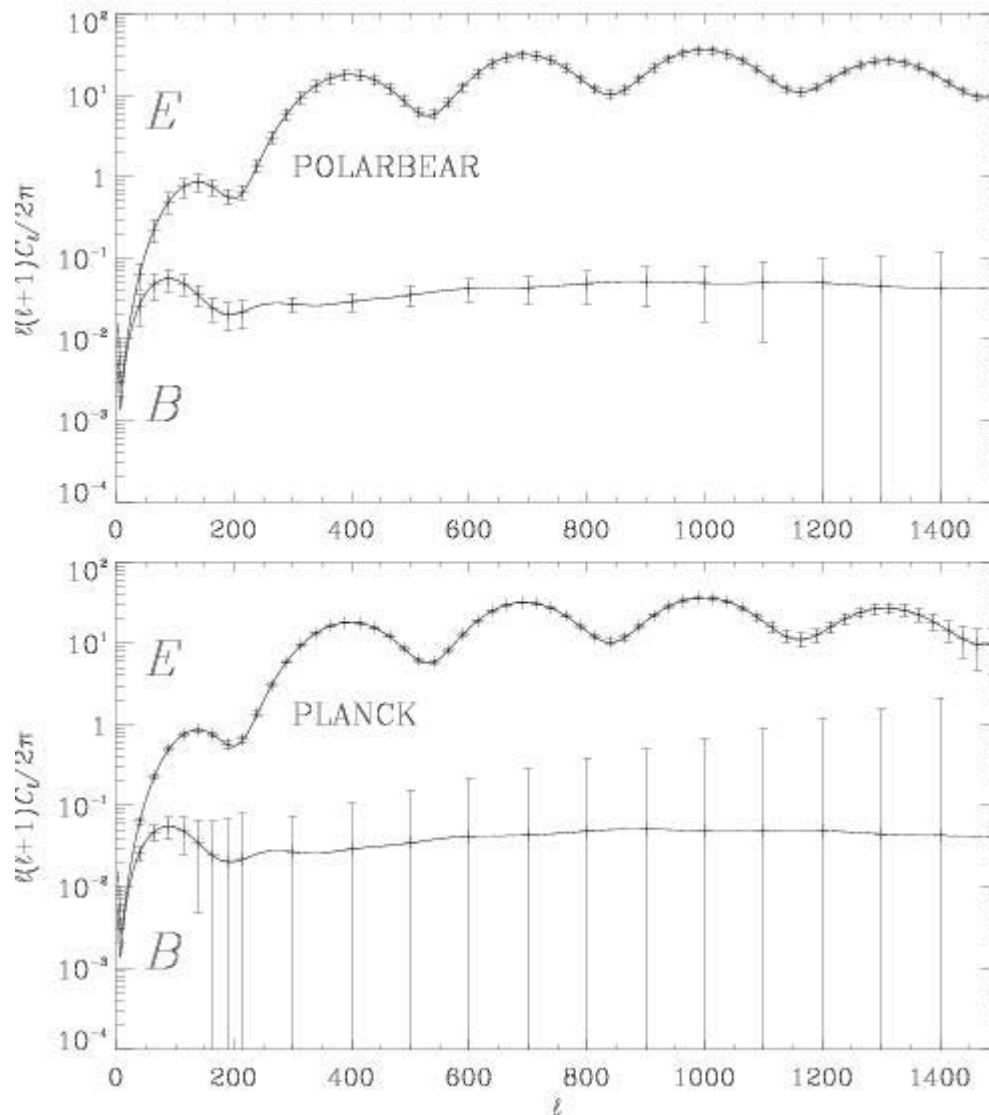
POLARBEAR

- Ground-Based 3 meter Telescope at White Mountain CA
 - Characterize E-modes
 - Search for B-modes
- First Light mid 2004
 - LDRD seed funding



POLARBEAR-I Performance

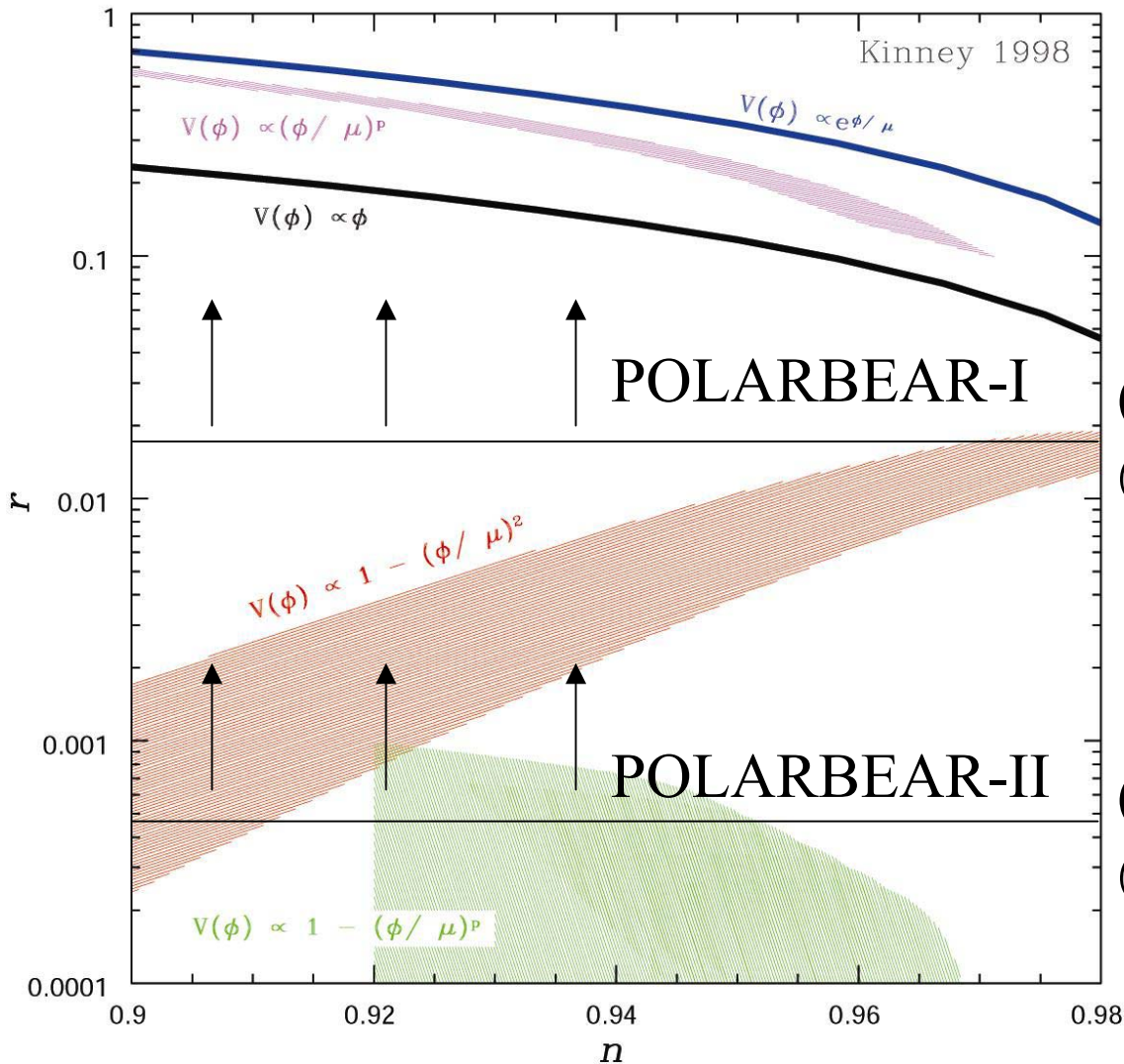
A.H. Jaffe



- 15 x 15 deg. observed
- 1.2 μ K rms per 5' pixel
- 200 nK rms per 30' pixel (re-pixelized map)
- T/S = 0.35 assumed

PolarBeaR Performance

r = tensor to
scalar ratio



n = tilt of primordial spectrum

ALMA Pathfinder Experiment (APEX)

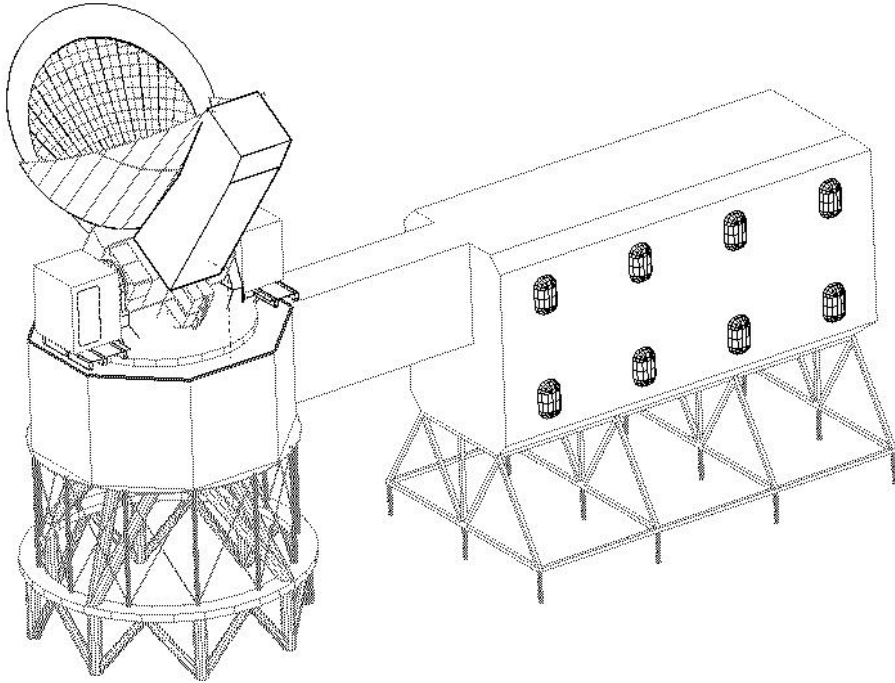


Telescope Specifications:

- 12 m on-axis ALMA prototype.
- 45'' resolution at 150 GHz.
- Located at 16,500 ft in the Chilean Andes.
- Telescope fully funded MPIfR/ESO/Onsala
- Assembly Begun in Chile!
- Berkeley Component NSF funded
- **First light 2004**

- 25% of Telescope time will be dedicated to Berkeley SZ Receiver

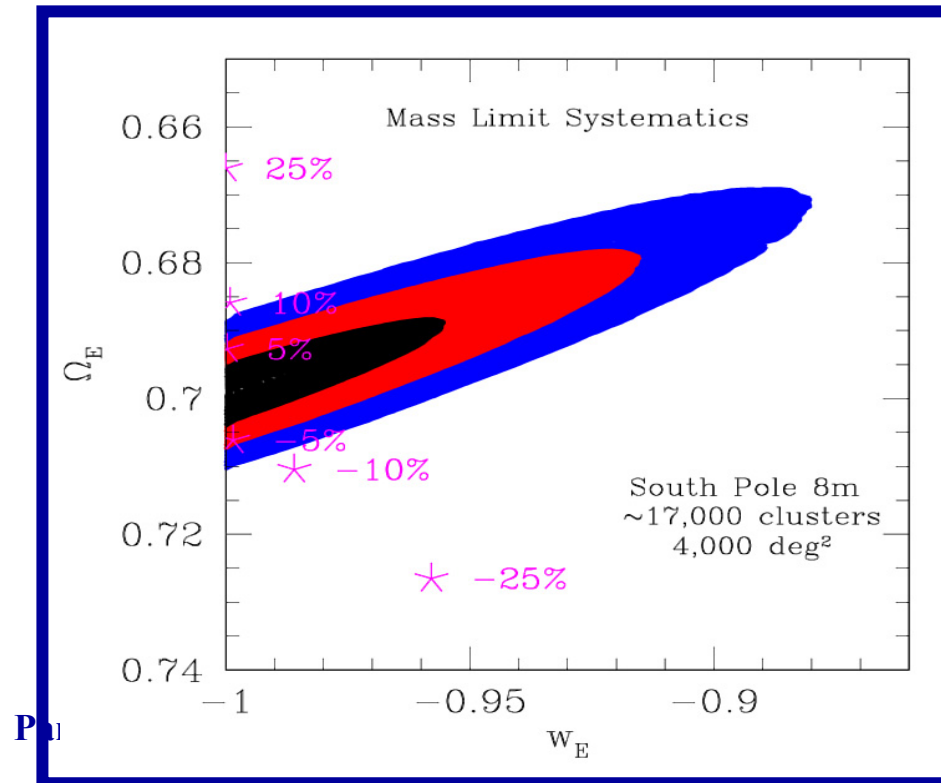
South Pole Telescope



- 8m, off-axis design
- 1.3' resolution
- 100% time SZ observations
- Best mm-wave site
- First light 2006-2007
- NSF Funded: Chicago, Berkeley, CWRU, SAO

APEX/SPT Complementarity: APEX will be operational 2-3 years before SPT, but SPT will have $\sim 5x$ faster cluster finding rate.

Dark Energy and Mass Limit Systematic Errors



$\Delta \log M$	Ω_E	$\langle w \rangle$	σ_8
+25%	0.6661	-1.0000	0.9539
+10%	0.6859	-0.9991	0.9231
+5%	0.6927	-0.9998	0.9124
0%	0.700	-1.0000	1.000
-5%	0.7061	-0.9985	0.8894
-10%	0.7105	-0.9860	0.8749 -
25%	0.7265	-0.9579	0.8305

CMB Polarization Satellite

- One of Three “Einstein Probes” will be “CMBPOL”
- Berkeley/LBNL/CIT/JPL Proposing Study
- LBNL infrastructure allows strong role for Berkeley

Data Analysis

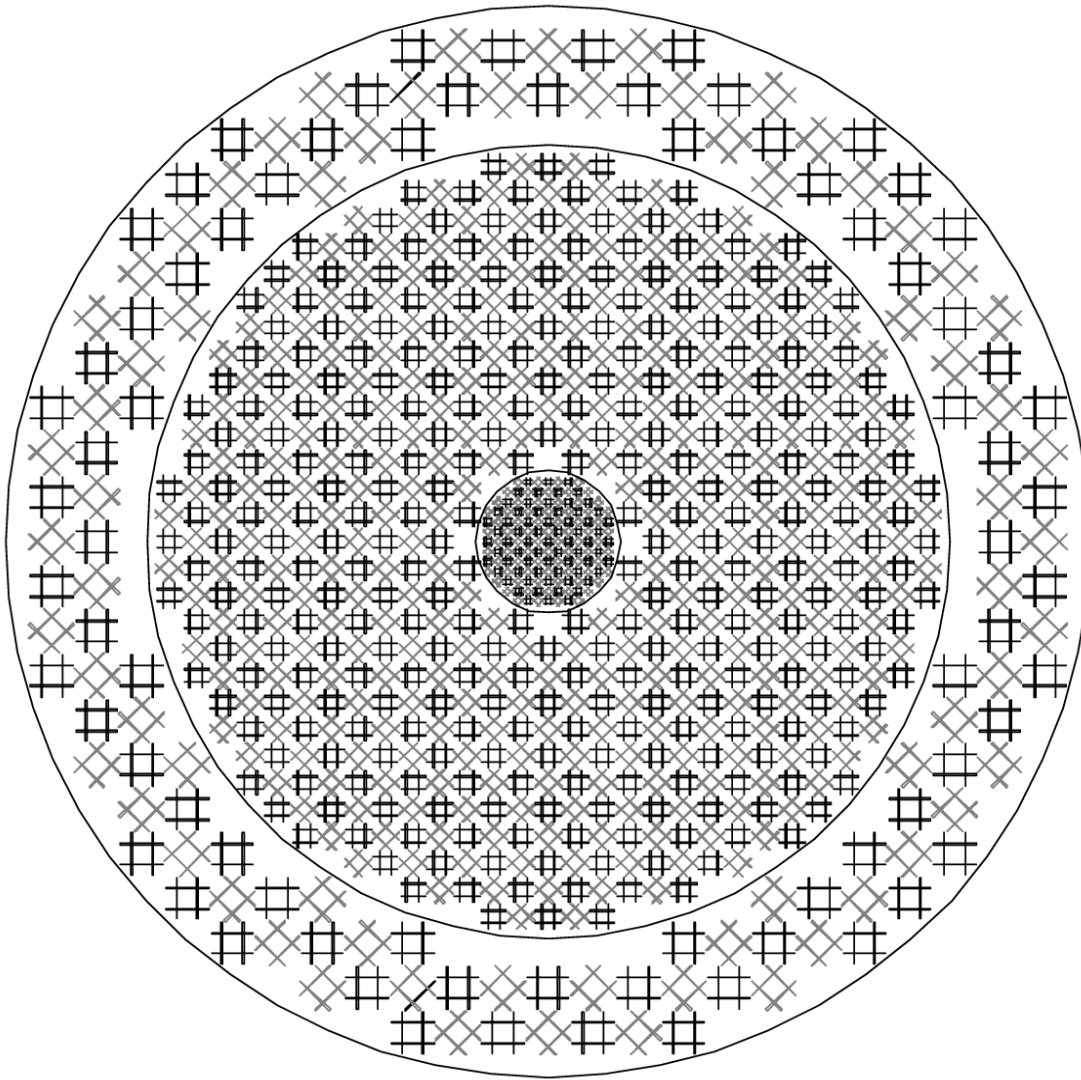
- NERSC has had strong role in MAXIMA/BOOMERanG
- Strong Group Built
- Critical for Future Experiments

Role of Physics Division

- Technical Advances Require Strong Lab Role
 - Readout Electronics for 10^3 - 10^4 pixels
 - Dedicated Thin-Film Fabrication Facility
 - Campus facility good for prototyping, but not production
- Complementary to SNIa work
- Larger Investment Required
 - LDRD Proposal for CMBPOL Prototype Submitted
 - Growth of CMB in Physics Division
 - Support for Thin-Film Facility

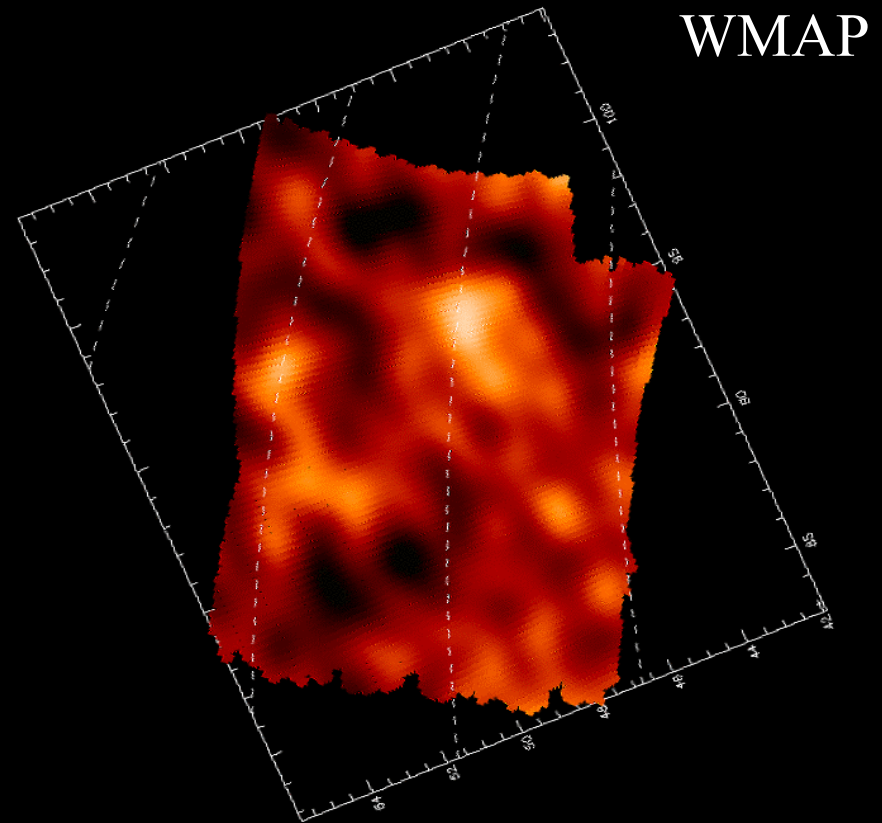
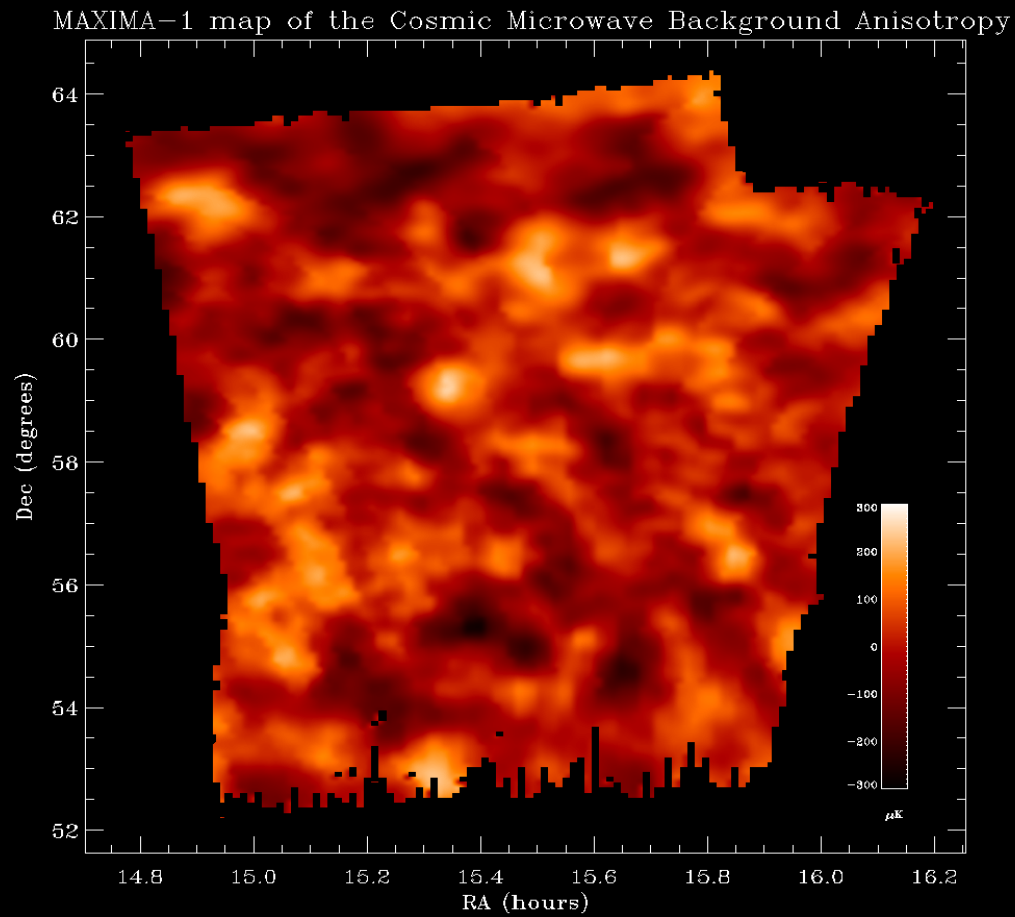
STOP

POLARBEAR focalplane



- 900 pixels @ 150 GHz, 3000 bolometers
- Full use of useful 150 GHz Field-of-view

MAXIMA-1 & WMAP



“Filtered” maps